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Literature Review Paper

Water Governance Under Pressure: Institutional Performance and Resource Management in Mexico

Gobernanza del agua bajo presión: desempeño institucional y gestión de recursos en México

David Humberto Sánchez Navarro[1*] y Carmen Julia Navarro-Gómez[1]

[1] Universidad Autónoma de Chihuahua. Circuito Universitario 31109, Campus Universitario II, C.P. 31125 Chihuahua, Chih. México.

*Correspondencia: Correo electrónico: dhsanchez@uach.mx (David H. Sánchez N.)
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Abstract

Mexico's water resources face challenges due to historical origins, socio-economic evolution, and environmental changes. Despite efforts, the water problem has worsened, leading to shortages, declining availability, and increasing demand. Factors contributing to these issues include limited budgets, lack of coordination, and planning-implementation gaps. This study analyzes the role of water institutions in Mexico and their impact on water management. The research aims to bridge knowledge gaps, provide insights into effective water management, and address the pressing water challenges, fostering a resilient water sector. The study's findings can guide decision-making, support the development of sustainable strategies, and enhance water resource management.

Keywords: **governance, water management, water crisis**

Resumen

Los recursos hídricos de México enfrentan desafíos debido a sus orígenes históricos, la evolución socioeconómica y los cambios ambientales. A pesar de los esfuerzos, el problema del agua se ha agravado, provocando escasez, disminución de la disponibilidad y aumento de la demanda. Entre los factores que contribuyen a estos problemas se incluyen los presupuestos limitados, la falta de coordinación y las deficiencias en la planificación e implementación. Este estudio analiza el papel de las instituciones del agua en México y su impacto en la gestión del agua. La investigación busca reducir las brechas de conocimiento, brindar perspectivas para una gestión hídrica eficaz y abordar los desafíos acuciantes en materia de agua, promoviendo un sector hídrico resiliente. Los hallazgos

del estudio pueden orientar la toma de decisiones, respaldar el desarrollo de estrategias sostenibles y mejorar la gestión de los recursos hídricos.

Palabras clave: **gobernanza, gestión del agua, crisis del agua**

1. Introduction

Water management represents a foundational pillar for achieving sustainable development and safeguarding public health. Ensuring the reliability and continuity of water supply systems is indispensable for the stability and functionality of modern urban and rural communities. However, accelerated urban expansion and the intensification of climate change impacts have substantially increased the complexity of water resource management. Challenges such as freshwater scarcity, aquifer depletion, and deterioration of water quality are no longer hypothetical scenarios but urgent global realities requiring coordinated, evidence-based responses. Moreover, rising population densities and the accelerated pace of urban sprawl have transformed cities into hotspots of vulnerability, amplifying the difficulty of delivering essential urban services and exacerbating pressure on existing water infrastructure (Martinez et al., 2015).

Several developing countries are putting their resources to intensive use, leading to overexploitation, contamination of their water resources, and the need to develop long-distance water imports. These countries have diminishing reliability of access to water, particularly for poor and isolated populations (Sánchez-Cohen et al., 2018). This is the case of Mexico, which has become a water-stressed country, especially in the arid and northern part of the country and in the principal megacities. Despite a long history of institutional reforms, Mexico is still unable to ensure adequate urban water services for its population, and its aquifers and ecosystems continue to deteriorate (Barkin, 2012). In terms of water resources, there is an enormous imbalance between water availability and its use. The main economic activities are concentrated in the central, northern, and northwestern regions of the country, representing approximately 83 % of the GDP and 77 % of the population, but with a per capita water availability of only 2,044 m^3/year (33 % of the country's water resources). On the other hand, in the south and eastern parts of the country, where water availability is 14,291 m^3/year per capita, only 17 % of the GDP is produced (Tortajada, 2006; CONAGUA, 2019). Beyond domestic use, agriculture and industry are central drivers of water stress in Mexico. Agriculture, often reliant on non-technological irrigation practices, accounts for the majority of national water withdrawals and contributes to aquifer overexploitation (Velasco-Muñoz et al., 2018). Industry also exerts significant pressure, both through intensive extraction (Water footprint network, 2024). These dynamics exacerbate the imbalance between water availability and demand, underscoring that water scarcity is not solely an urban or domestic challenge (Amoah et al., 2021), but a systemic issue linked to economic production and environmental sustainability.

In this context, water management in Mexico becomes problematic due to the inverse relationship resulting from three factors: the distribution of water resources, the contribution to the national production of each region, and the demographic concentration (Nava, 2006), fabricating significant challenges to provide water services for its population (Arriaga-Medina & Piedra-Miranda, 2021). The technical, institutional, and economic-financial problems presented by virtually all drinking water suppliers in the country are translated into insufficient, irregular, and low-quality supply (González-Villarreal & Arriaga-Medina, 2014).

Mexico has achieved certain important goals in terms of the supply and coverage of potable water; nonetheless, there are still profound variances between the different agencies in efficiency and effectiveness. Water institutions need to accommodate physical, economic, institutional, and political constraints for a durable and holistic approach to improve the role of the Water Utilities (WU) (Saleth, 2014). Therefore, it is critical to analyze and understand the role of water institutions and their impact on the water sector performance in Mexico (Chopra & Ramachandran, 2021). However, there is limited information in the literature on drinking water management description in Mexico (Silva et al., 2018). Given the existing limitations and gaps in the literature regarding institutional frameworks in the water sector in Mexico, this study aims to analyze the role of water institutions and their influence on several dimensions of water sector performance in Mexico. This manuscript analyzes the current state of water resources management in the country, highlighting the principal institutional, regulatory, and operational challenges facing the sector. This study seeks to enhance understanding of institutional dynamics and promote informed decision-making. Ultimately, it aims to support the development and consolidation of effective water governance mechanisms that enable the sustainable and equitable management of water resources.

2. The Water Sector in Mexico: A Multidimensional Perspective

2.1 Characteristics of Mexico

Mexico ranks among the fifteen most populous countries globally and holds a similar position in terms of GDP. With a land area of approximately 1,964 million km^2, it is the fourteenth largest country by surface area (World Bank Group, 2023). The country's geographic diversity, shaped by its wide latitudinal extent, complex topography, and climatic variability, directly influences the distribution and availability of its water resources. The southern portion of the territory lies within the intertropical zone, while the north falls within the temperate zone, placing much of the country along latitudes comparable to those of the Sahara and Arabian deserts. These geographic and climatic conditions result in pronounced hydrological heterogeneity. Approximately two-thirds of the territory is classified as arid or semi-arid, receiving less than 500 mm of precipitation annually. In contrast, the southeastern region is characterized by a humid climate, with annual rainfall exceeding 2,000 mm. The national mean annual precipitation is approximately 760 mm, which is significantly lower than the global average of 1,127 mm (CONAGUA, 2024). Precipitation is highly seasonal, with most rainfall occurring during the summer months, typically as intense convective storms (García, 2004; Aguilar-Barajas et al., 2016). This uneven spatial and temporal distribution of water presents substantial challenges for water management, particularly in northern and central regions where surface water is scarce and groundwater is often overexploited.

As of December 2020, Mexico is administratively divided into 32 states comprising a total of 2,453 municipalities and 16 mayorships. These political divisions further influence water governance structures and resource allocation at the regional and local levels. There are 92 metropolitan areas, which estimate 82.5 million inhabitants, constituting 65.5 % of the projected population for 2023 (CONAGUA, 2024). The process of concentration of inhabitants in urban and semi-urban has accelerated strong stress on the environment given the increased demand for services (Tortajada, 2006). In Mexico, almost one-third of households in rural communities with populations below 2,500 lack potable water, and more than 63 % do not have basic, water-related services (CONAGUA, 2024).

Furthermore, most rural communities in Mexico exist under very dry or dry conditions, with an accentuated social lag that also inhibits economic development (Sánchez-Cohen et al., 2018). As stated by Cervantes-Jiménez et al. (2020), in Mexico, the extreme conditions of socio-economic inequality are undoubtedly reflected; these heavily marginalized areas have low economic productivity, high unemployment and outmigration rates, and poor access to services like clean water and sanitation (Tortajada, 2006).

2.2 Availability, variability, and water demand

Water resource availability in Mexico exhibits significant spatial and temporal variability, shaped by climatic heterogeneity, physiographic complexity, and uneven demographic and economic development. These conditions present considerable challenges for the effective regulation, allocation, and sustainable management of water resources at both national and regional levels. In regions where surface water is irregular and cannot be relied upon as a continuous source, aquifers become the primary supply, as is the case in much of northern Mexico. During drought periods, demand typically intensifies as users compensate for reduced surface availability, often leading to aquifer overexploitation. This situation highlights the need for adaptive management strategies that are able to reconcile fluctuating natural availability with the relatively constant demands of urban, agricultural, and industrial sectors.

The National Water Commission (CONAGUA), Mexico's principal authority for water governance, carries out its administrative, regulatory, technical, and advisory functions through 13 Basin Organizations (CONAGUA, OECD, and IMTA, 2010). These entities are aligned with the Hydrological Administrative Regions, which consist of grouped river basins that serve as operational units for integrated water management. To facilitate the integration of hydrological and socioeconomic information, the boundaries of the RHAs were delineated in accordance with municipal divisions.

Mexico contains approximately 1,471 river basins and 653 officially recognized aquifers, distributed across 13 administrative regions and 37 hydrological subregions (CONAGUA, 2022). However, the availability of renewable water is not aligned with the distribution of population or economic activity. While the southern and southeastern parts of the country receive most of the surface water due to higher rainfall, the central and northern regions, where more than half of the population resides, frequently experience water scarcity and mounting pressure on supply systems.

Groundwater serves as a vital source of supply, particularly in arid and semiarid zones where surface water is either limited or seasonally variable. As of January 2018, only 408 of the 653 aquifers had a positive water balance, reflecting a 37 % decline in groundwater availability due to long-term overextraction and reduced natural recharge (Arreguín-Cortés et al., 2020). Groundwater availability remains a key variable for the assignment of national water rights through concession and permitting systems.

Mexico receives an average of 1,449,471 million m^3 of precipitation annually. However, this input is highly seasonal, with approximately 68 % of total rainfall occurring between June and September. This concentration of rainfall presents major challenges for storage, regulation, and year-round distribution. Of the total precipitation, around 72.1 % is lost to evapotranspiration, 21.4 % flows as surface runoff, and only 6.4 % infiltrates to recharge aquifers. After accounting for cross-border water exchanges, the country's annual volume of renewable freshwater is estimated at 451,584.7 million m^3 (CONAGUA, 2022). From a geographic perspective, national-level indicators tend to obscure local disparities that are critical for operational water management. In 2023, the estimated per capita renewable water availability was 3,569 m^3/inhab/year, although this average does not reflect wide variation among hydrological regions (IMCO, 2023).

The imbalance in water distribution, with a dry northern half and a wetter southern portion, creates a complex scenario for water governance. Even in areas with relatively abundant water, challenges such as pollution, inefficient use, and infrastructure deficiencies persist. As a result, water management in Mexico is shaped not only by physical scarcity but also by structural mismatches between water supply, economic activity, and population distribution (Nava, 2006). These issues are further intensified by the continued overexploitation of aquifers, which undermines the long-term sustainability of the country's water resources. Water demand in Mexico reflects this uneven distribution of resources. Agriculture accounts for nearly three-quarters of total withdrawals, largely concentrated in arid and semi-arid regions where irrigation is essential, while urban and industrial demand has risen steadily due to population growth and economic expansion in water-scarce central and northern areas (Bravo-Cadena et. al, 2021; CONAGUA, 2024). This imbalance between resource availability and demand intensifies competition among users, contributes to groundwater overexploitation, and complicates efforts to ensure equitable and sustainable allocation across sectors.

2.3 Water legal framework

The governance of water in Mexico is grounded in the Political Constitution of the United Mexican States, which establishes a decentralized legal framework involving the federal, state, and municipal levels of government. Article 27 affirms that national waters are the property of the Nation, under the custody and administration of the federal government. Article 4, paragraph 6, formally recognizes access to water and sanitation as a human right, guaranteeing that all individuals are entitled to sufficient, safe, acceptable, and affordable water for personal and domestic use (Cámara de diputados del H. Congreso de la Unión, 2021).

Crucially, Article 115 delegates to municipal governments the responsibility for providing public services, including the supply of drinking water, drainage, sewage, treatment, and the disposal of wastewater. Section III (a) of this article enables municipalities to manage these services directly or through the establishment of decentralized operating agencies—public, private, or mixed—created by municipal decree and formalized in official gazettes (Cámara de diputados del H. Congreso de la Unión, 2021). This legal framework defines a multilevel governance system in which the federal government retains ownership and regulatory control over water resources, with the National Water Commission (CONAGUA) serving as the principal federal authority. At the same time, states and municipalities are responsible for implementation, service provision, and infrastructure operations at the local level.

2.4 Water laws

Building upon constitutional mandates, Mexico's water governance is shaped by a series of federal legal instruments that define the mechanisms for water allocation, regulation, use, and protection. The National Water Law (LAN) serves as the foundational legal statute for managing national waters. It establishes the principles and institutional arrangements for integrated water resource management, requiring that all extractions and discharges be authorized through concessions issued by the National Water Commission (CONAGUA). The LAN also provides legal tools to ensure hydrological sustainability, including the declaration of prohibitions in overexploited areas, the establishment of reserves for ecological or public use, and the issuance of regulations that define conditions for water use under specific hydrological or ecosystem contexts (CONAGUA, OECD, and IMTA, 2010).

Complementing this framework, the Federal Rights Law (LFD) defines the financial architecture of water management in Mexico. It determines the allocation of abstraction and pollution discharge fees, sets the boundaries of water availability zones, and operationalizes the principles of "user pays" and "polluter pays." Article 223 of the LFD stipulates that revenues generated from the use of national waters are allocated to the Federation and earmarked for investments in hydraulic infrastructure and sectoral programs (CONAGUA, OECD, and IMTA, 2010). First enacted in 1981 and most recently amended in 2022, the LFD has become a central fiscal tool for incentivizing efficient and equitable water use.

Regulatory oversight is further reinforced by Mexican Official Standards (NOMs), which define enforceable parameters for water quality, wastewater discharges, service provision, and operational safety. Several NOMs explicitly regulate both surface and groundwater, establishing maximum permissible concentrations of contaminants, sanitary monitoring protocols, and technical guidelines for discharge control. These technical instruments provide the methodological basis for compliance monitoring, risk mitigation, and performance benchmarking for water utilities and public agencies. The most relevant include NOM-127-SSA1-2021 (Diario Oficial de la Federación (DOF), 2022), which sets maximum permissible limits for contaminants in drinking water; NOM-001-SEMARNAT-2021 (Diario Oficial de la Federación (DOF), 2022), which regulates pollutant discharges into national water bodies; and NOM-014-CONAGUA-2003 (Diario Oficial de la Federación (DOF), 2003), which establishes criteria for artificial recharge of aquifers. Compliance is enforced through a combination of monitoring programs, concession requirements, and inspection mechanisms carried out by CONAGUA and health authorities.

At the state level, additional legislation supports the decentralization of water services. Each federal entity enacts a Drinking Water and Sewerage Law, which outlines the institutional arrangements for service delivery and, in some cases, authorizes the creation of autonomous public bodies to manage water supply and sanitation systems. These laws help align state policies with federal legislation while addressing local governance and infrastructure realities (Camacho & Casados, 2017).

2.5 Institutions and Water Utilities (WU)

The institutional architecture of the water sector in Mexico involves a wide range of actors operating at different levels of government. At the federal level, the National Water Commission

(CONAGUA) serves as the lead agency responsible for issuing water use concessions, monitoring regulatory compliance, managing federal hydraulic infrastructure, and formulating the National Water Program, which sets strategic policy objectives for each six-year federal administration. CONAGUA also interfaces with state and municipal authorities, coordinates basin-level management through its regional organizations, and oversees the implementation of reserves, prohibitions, and regulatory zones. CONAGUA is responsible for integrating the National Water Information System (SINA), which compiles standardized data on water quantity, quality, use, and conservation in line with transparency and statistical legislation.

Other federal institutions play important roles in water governance. The Ministry of Finance and Public Credit (SHCP) is responsible for fiscal regulation and authorizes CONAGUA to collect water use fees. The Federal Congress reviews and approves legal amendments and national water budgets. Agencies such as the National Infrastructure Fund (FONADIN), the Federal Attorney for Environmental Protection (PROFEPA), and the Welfare Secretariat support infrastructure financing, environmental enforcement, and social water programs. The Mexican Institute of Water Technology (IMTA) contributes to the system by generating research, innovation, and capacity-building tools for water resource sustainability (CONAGUA, OECD, and IMTA, 2010).

At the state level, governments are responsible for planning, regulation, infrastructure development, and in many cases, direct service provision. State legislatures may determine tariff structures, although some states delegate this authority to technical commissions or specialized regulatory bodies, such as the Chihuahua Central Water and Sanitation Board (JCAS), which oversees tariff setting and supervises municipal water utilities (H. Congreso del Estado, 2023).

Municipalities are the legally mandated providers of drinking water, sewerage, and sanitation services, as established by Article 115 of the Constitution and reinforced by the 1983 constitutional reform (Cámara de diputados del H. Congreso de la Unión, 2021). To fulfill this role, many municipalities have created decentralized water utilities (WU) with their own legal status, financial autonomy, and administrative capacity. These agencies are responsible for service delivery, fee collection, infrastructure maintenance, and in some cases, wastewater treatment and reuse.

WU are key operational actors in the sector, particularly in urban areas. In densely populated regions, para-municipal organizations manage service delivery, exhibiting a wide range of technical, commercial, and financial capacities. While a few utilities have achieved institutional consolidation and financial self-sufficiency, the majority face challenges related to underinvestment, inefficiencies, and limited operational autonomy. Private participation in the sector remains marginal, with only a few concessions operating in major metropolitan areas (Barkin, 2005). Despite these challenges, WUs remain central to the realization of the human right to water and the implementation of national and state water policies (Camacho & Casados, 2017).

3. Water management challenges in Mexico

3.1 Scarcity, vulnerability, quality, and future demand

Water scarcity in Mexico arises from a combination of governance and socioeconomic inequalities, regional imbalances in availability and demand, and mounting pressures from climate variability and population growth. These interrelated factors have deepened the country's vulnerability to hydrological stress. Water use in urban areas illustrates pronounced socioeconomic disparities. High-income neighborhoods in large cities often consume more than 300 l/inhab/day, far exceeding international benchmarks (Magaña et al., 2024). Meanwhile, marginalized communities in the same cities frequently face deficient service coverage and fall below minimum recommended supply levels. This imbalance reflects not only distributional inequality, but also a long-standing reliance on supply expansion as the dominant water management strategy. Rather than addressing demand through efficiency measures or behavioral change, authorities have historically focused on increasing water availability to satisfy rising consumption (Aguilar-Barajas & Ramírez, 2021; Medina-Rivas et al., 2022). This approach has contributed to chronic water deficits over time and has led to socioeconomic drought conditions, even in the absence of meteorological drought (Magaña, 2016). In 2020, agriculture accounted for nearly 77 % of national withdrawals, followed by industry (approximately 10 %) and domestic use (13 %) (CONAGUA, 2022), illustrating how sectoral demand patterns intensify pressure on already scarce supplies.

Sustainable water resource management in Mexico must consider three critical dimensions: temporal variability, spatial distribution, and scale of analysis. Rainfall is highly seasonal, with most precipitation concentrated between June and September, generating significant intra-annual variability. Regions such as the southeast receive abundant rainfall but host relatively low population densities and limited demand. Conversely, arid and semi-arid zones in the north and center experience chronic water stress. From a governance perspective, water challenges are primarily local. National averages often mask acute subregional disparities, highlighting the need for basin-level diagnostics and targeted, locally adapted interventions (Mekonnen & Hoekstra, 2011).

The agricultural sector, which accounts for approximately 77 % of total water withdrawals, remains a major source of pressure on available water resources (Bravo-Cadena et al., 2021). Despite its economic relevance, the sector faces increasing pressure to improve productivity with less water in response to population growth and shifting climatic conditions. Water stress is particularly severe in the northern and central regions, where high demand intersects with limited natural supply and recurring drought conditions (Aguilar-Barajas et al., 2016; Cotler et al., 2022).

Additional pressure stems from the weak enforcement of water rights and concessions. In some basins, withdrawals exceed authorized volumes, or water allocations are granted despite insufficient hydrological availability. These challenges are compounded by extreme events such as droughts and hurricanes, which further disrupt surface and groundwater systems. Although the country's national water stress level is reported at 17 %, regional disparities are much more pronounced. The north, northwest, and central regions experience stress levels approaching 47 %, indicating critical vulnerability (CONAGUA, 2019; Arreguín-Cortés, et al., 2020).

Long-term trends also show declining per capita water availability. Over the past five decades, average renewable water availability per inhabitant has decreased by approximately 18,500 m^3 per year (CONAGUA, 2019). Mexico City is one of the most vulnerable regions, with the lowest average annual availability of water per capita, estimated at only 141 m^3/inhab/year. This is a significant contrast to Chiapas, which has the highest renewable water availability, with 19,140 m^3/inhab/year (CONAGUA, 2024).

Moreover, Mexico is grappling with challenges related to quality. Pollution from agricultural activities and untreated sewage has led to environmental damage and health problems (Bravo-

Cadena et al., 2021). Water contamination is limiting the availability of water, with 70 % of water bodies exhibiting some degree of contamination, as reported by the surface water quality measurement network in Mexico by CONAGUA (Arreguín-Cortés et al., 2020). This monitoring program evaluates a range of physical, chemical, and biological parameters (such as nutrients, heavy metals, organic matter, and microbial indicators), which together provide the basis for reporting contamination levels across the country. Additional pressure also stems from the degradation of rivers due to untreated municipal wastewater, industrial effluents, and diffuse agricultural pollution. Although Mexican Official Standards, such as NOM-001-SEMARNAT-2021, regulate wastewater discharges and NOM-127-SSA1-2021 establishes drinking water quality criteria, setting enforceable parameters, monitoring, and compliance remain limited. Many discharges exceed permissible limits without sanction, and enforcement responsibilities are often fragmented between CONAGUA, Ministry of Environment and Natural Resources (SEMARNAT), and state authorities. This institutional weakness, coupled with insufficient inspection capacity, results in limited accountability for contamination and undermines the effectiveness of the legal framework in protecting water quality.

Future water demand poses an additional challenge. Mexico’s population is projected to grow from 126.2 million in 2020 to 151.4 million by 2050, representing an increase of more than 20 % (United Nations, 2019). Consequently, water demand in all sectors is expected to rise, leading to increased water stress in some regions. This situation is particularly concerning in the central and northern regions, which are already experiencing high levels of water stress.

3.2 Politics and policies discrepancy

There is an increasing number of conflicts and competition for water, involving the three levels of government and water users. Transboundary basins and aquifers further exacerbate the situation, leading to disputes. To manage water resources effectively, the legal framework needs updating as it is complex and difficult to implement (Arreguín-Cortés et al., 2020). One of the major issues is the subsidized price for pumping underground water for irrigation, which provides incentives for increasing the volume of water pumped (Rosas & Günther, 2020). This policy needs coordination with other sectors, such as agriculture. Another critical issue is the efficiency of irrigation infrastructure, which causes significant losses and exacerbates water use (CONAGUA, OECD, and IMTA, 2010; Bravo-Cadena et al., 2021).

According to Rosas and Günther (2020), reducing the number of water permits available for irrigation is essential to reduce water stress. However, this is politically difficult as it would reduce the surface available for agriculture. Water users must change their perception of aquifers and recognize them as a reserve for periods of scarcity, rather than an ordinary source of water. Given the circumstances, Mexico developed a framework for allocating water resources due to the need to distribute limited water among a diverse group of users. However, authorities face challenges in regulating large water users and managing the culture of irresponsibility among consumers who do not pay for water use (Barkin, 2012).

The technical and political features of the Mexican system exacerbate the problem of the allocation of water resources. Constitutionally, water resources are owned by the nation and subject to political control. With the urban expansion and industrial growth, new water demands have led to the emergence of a lucrative "parallel" market, leading to the transfer of some of these water rights for commercial and industrial purposes (Barkin, 2005; Barkin, 2012). Despite having a range of laws and regulations governing water resources, there is often weak enforcement and monitoring of compliance, which can lead to abuses and overexploitation of water resources.

3.3 Technical and operational challenges of WU

The human right to water is a fundamental element that has been established by various international treaties and declarations and is reinforced by the laws of Mexico. This constitutional mandate has significant legal and technical implications on the water sector in Mexico (Camacho & Casados, 2017). According to Briseño and Sánchez (2018), WU were established to address the longstanding difficulties in the political management of water services.

These organizations were designed to strive for characteristics such as autonomy, democratization of administrative councils, reinvestment of resources captured in the collection of water, approval of rates by boards of directors, financial self-sufficiency, and greater technical and administrative capacity. However, the decentralization of water management in Mexico has not met the ideal profile, resulting in unsatisfactory performance by several organizations (Barkin, 2005; Barkin, 2012; Briseño & Sánchez, 2018; Arreguín-Cortés et al., 2020). The performance of these institutions mismatches between ecosystem processes and management scales, for example, the rules, laws, policies, and formal and informal cultural norms, which govern the spatial and temporal extent of resource access rights and management responsibilities (Cotler et al., 2022). According to Camacho and Casados (2017), the institutional framework in which the water utilities operate does not promote efficiency; key players do not aim for good performance, and selection methods and criteria do not consider technical factors (Salazar-Adamas, 2021).

3.4 Financial challenges of WU

The financial sustainability of WU in Mexico remains a critical bottleneck to achieving universal, efficient, and equitable water services. One of the central institutional mechanisms for managing water finances is the fee system for water abstraction and discharge, which is regulated by CONAGUA. Any use of national waters requires a permit from CONAGUA, which collects these fees and redistributes them for infrastructure development and water management programs (CONAGUA, OECD, and IMTA, 2010).

Despite this system, WU across the country faces systemic financial challenges. The most pressing issue is the lack of full cost recovery through user fees, which hinders their capacity to cover operational costs and severely limits their ability to secure third-party or commercial financing. As a result, the sector remains heavily dependent on government subsidies sourced from tax revenue, petroleum royalties, and earmarked federal programs managed by CONAGUA (CONAGUA, OECD, and IMTA, 2010; Silva Rodríguez, 2017).

Billing inefficiencies exacerbate this challenge. A significant proportion of WUs continue to rely on analog metering technologies and manual billing processes, characterized by measurement errors, unaccounted-for water, and revenue losses. In many municipalities, the absence of automated or digital billing platforms restricts consumer access to real-time consumption data and inhibits timely payment. These systemic inefficiencies contribute to elevated non-revenue water levels and suboptimal cash flow (IMCO, 2023). These challenges are provoked by user-side non-payment, often linked to low tariffs and politically tolerated, and from weak enforcement mechanisms by authorities, resulting in a structural imbalance that prevents WUs from achieving cost recovery and entrenches their dependence on subsidies.

Subsidy schemes also demonstrate poor allocative efficiency. In practice, generalized subsidies disproportionately benefit high-consumption users—especially in the agricultural sector—fostering perverse incentives for over-abstraction and contributing to the depletion of aquifers (Briseño & Sánchez, 2018). The absence of income-targeted subsidies undermines equity and fails to prioritize vulnerable populations, such as low-income households and smallholder farmers. Moreover, spatial asymmetries in financial management are evident: some federative entities collect relatively high volumes of water-related revenues but exhibit low reinvestment ratios in hydraulic infrastructure or service quality improvements (IMCO, 2023). In recognition of these constraints, national authorities have promoted mechanisms to attract private sector engagement and mobilize commercial finance (Camacho & Casados, 2017). Nonetheless, private capital flows into the water sector remain negligible. Investment has primarily occurred via public grants and co-financing schemes administered by CONAGUA. WU, constrained by weak credit profiles and fiscal rigidity, faces difficulties in accessing capital markets or obtaining project-based loans. In several instances, municipal governments have resorted to general-purpose debt issuance to cross-subsidize water infrastructure, albeit without long-term sustainability plans.

Budgetary allocations at the federal level further illustrate the sector's fiscal fragility. In 2020, the approved federal budget for water and sanitation infrastructure totaled 6,938 million pesos—representing only 9 % of the estimated financing needs identified by the National Association of Water and Sanitation Utilities (ANEAS, 2020). The historical trajectory of public investment in the sector reveals a downward trend; between 2012 and 2020, federal budget allocations declined by nearly 80 %, constraining expansion, rehabilitation, and climate resilience planning (ANEAS, 2020). Operational deficits are widespread. According to estimates from IMTA and SEMARNAT (2018), 90 % to 95 % of municipal water utilities operate in deficit, unable to recover the economic cost of service provision. Underinvestment in infrastructure correlates with reduced continuity, water quality issues, and declining user satisfaction. These challenges are magnified by exogenous pressures, including accelerated urbanization, demographic growth, climate variability, and social conflict over water rights and allocation (Cotler et al., 2022). Local political dynamics and fiscal constraints further inhibit WU's capacity to adjust tariffs, restructure debt, or upgrade infrastructure. Addressing these constraints requires a multifaceted strategy involving tariff reform, metering modernization, digital infrastructure investment, results-based subsidies, and improved fiscal coordination among federal, state, and municipal levels.

3.5 Socio administrative vulnerability

Mexico's water resource management is facing significant vulnerability due to inadequate social participation and limitations in the current administration model. These issues arise from the lack of clarity in regulations, roles, organizational structures, and coordination mechanisms among various actors involved in environmental matters. Furthermore, inadequate cooperation and coordination among government levels, sectors, public and private actors, and the absence of participation by social and private actors in decision-making processes exacerbate the situation

(Rosas & Günther, 2020). Minimal transversality of strategies and actions in other sectors of the economy and the water authority further adds to the problem (Barkin, 2012; Pfaff et al., 2019; Rosas & Günther, 2020).

Although Mexico has experience managing watersheds in rural areas with a strong emphasis on community governance, expanding these efforts to include urban centers in the watershed management process is a major challenge. Achieving this goal requires the creation of new collaborative governance structures that can effectively engage with city governments and other urban stakeholders.

A more holistic ecosystem approach to water and development is needed, maintaining a beneficial mix between natural and man-made infrastructure to maximize benefits. Conflicts in the water and sanitation sector often originate from chosen economic and social development models, leading to questions about the legitimacy and functions of institutions and precepts contained in various laws and regulations. Bureaucratic design that hinders agility in decision-making creates fertile ground for social conflicts in the water and sanitation sector (Barkin, 2012; Arreguín-Cortés et al., 2020). To address these issues, greater participation by users is needed to communicate to stakeholders the need to compromise on measurement, efficiency, and actions based on a basin-wide vision.

However, the latest reform to the National Water Law (2023) falls short in terms of promoting effective public participation. While representatives of users and organized society are allowed to attend meetings of the Basin Council and the Consultative Council of the Basin Organization, they only have a voice and no vote. Similarly, the General Assembly of Users is limited to issuing recommendations (ANEAS, 2008). Despite the multiple benefits of water representatives and organized society, their potential cannot be achieved without the participation of authorities and water users.

4. The way forward

4.1 Enhance water infrastructure and the development of new storage reservoirs

Recent trends in public spending on the water sector in Mexico reveal an imbalanced allocation of financial resources, with a disproportionate emphasis on the construction of new hydraulic infrastructure and insufficient investment in its operation, maintenance, and management (Arreguín-Cortés et al., 2020). To ensure long-term water security, it is essential to prioritize the modernization of existing infrastructure, expand water storage capacity through the development of new reservoirs, and improve the operational efficiency of distribution networks. The deterioration of aging infrastructure represents a critical challenge. According to IMTA and SEMARNAT (2018), approximately 50 % of municipal hydraulic networks require renewal due to the expiration of their regulatory service life, largely attributable to prolonged neglect and underfunding. Targeted investments in rehabilitation and preventive maintenance are therefore essential to restoring the reliability and functionality of water systems.

According to data reported by CEPAL (2023), public investment in the water sector, excluding expenditures by utilities or state governments, indicates that between 2018 and 2020, a total of USD 3.5 billion was allocated to the sector. PROAGUA is a federal subsidy program designed to expand

and strengthen municipal water and sanitation services. Between 2018 and 2020, it disbursed USD 224 million in rural areas, USD 443 million in urban areas, and USD 151 million to support the comprehensive development of utilities, wastewater treatment plants, and water disinfection systems. PRODDER is a federal program that allocates revenues collected from fees for the abstraction and use of national waters back to water and wastewater service providers. These revenues are collected by CONAGUA under the Federal Rights Law as payments for the right to use national waters. These funds are returned to WU providers to improve operational efficiency and invest in drinking water, sewage, and wastewater treatment infrastructure. From 2018 to 2020, PRODDER allocated USD 605 million to such initiatives (Fernández, et al., 2023).

Despite these efforts, total public investment in the sector declined by 41 % over the same period. The reduction in federal transfers alone accounts for a 36 % drop compared to 2018, equating to a decrease of USD 5.12 per capita. This downward trend is particularly concerning in the context of aging infrastructure, population growth, and increasing climate variability.

Achieving sustainability in water resource management requires stable and sufficient funding. From 2014 to 2018, CONAGUA's annual budget fell from 55.6 billion to 32.3 billion pesos (CONAGUA, 2019). Nonetheless, fiscal instruments linked to the abstraction and use of national waters have demonstrated revenue-generating potential. Between 2012 and 2018, revenues from user contributions consistently exceeded the financial requirements of governmental water programs, reflecting a net surplus in the water governance budget (Fig. 1). This suggests that, with appropriate mechanisms, the sector possesses untapped financial capacity to meet infrastructure demands and strategic water management goals.

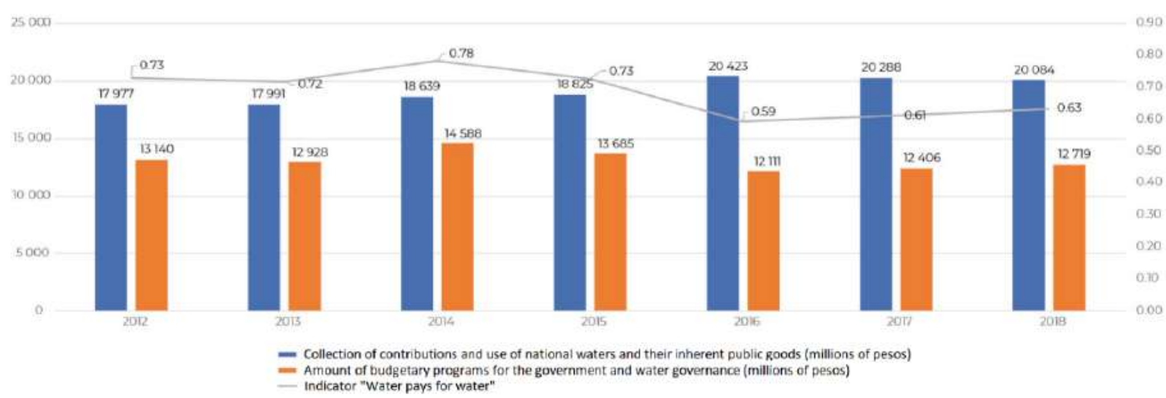

Figure 1. Relationship between budgetary programs tied to government and water governance with respect to revenue collection, indicator "Water Pays for Water" (at constant 2018 prices). (CONAGUA, 2019).
Figura 1. Relación entre los programas presupuestarios vinculados al Gobierno y la gobernanza del agua con respecto a la recaudación de ingresos, indicador «El agua paga por el agua» (precios constantes de 2018). (CONAGUA, 2019).

To optimize resource utilization, investments should prioritize the implementation of water conservation measures, promotion of efficient water use practices, and exploration of alternative water sources, such as wastewater recycling and desalination. Arreguín-Cortés et al. (2020) estimate that achieving sustainability and water security in Mexico would require at least 24 years of investment, until 2042, with an infrastructure cost of 48.8 billion pesos. Furthermore, the costs of operation and maintenance of existing works, estimated at 17 billion pesos, must be considered. It is also necessary to allocate resources for water administration and law enforcement, measurement of the hydrological cycle, water planning, social participation, research, education, and capacity building, as well as promoting a water culture. Collaboration among governments, international organizations, and private entities is essential to secure the necessary financial resources and ensure their effective allocation and utilization. To reinforce accountability and encourage responsible water usage, it is imperative to direct proceeds from water usage fees and discharges directly to the water sector.

4.2 Ensuring controlled groundwater pumping

The uncontrolled pumping of groundwater presents a significant challenge in water resource management. Addressing this issue requires the implementation of strict regulations and monitoring systems to effectively manage and regulate the extraction of groundwater resources, thereby preventing overexploitation and depletion (Janjua et al., 2021). This includes the establishment of extraction limits and the promotion of sustainable groundwater management practices through awareness campaigns and policy interventions (Zamora Sáenz & Sánchez Gálvez, 2020). Another critical aspect to consider is the improvement of irrigation infrastructure efficiency. Currently, irrigation networks experience considerable losses, and given that irrigation accounts for most of the water use in Mexico, better management of irrigation practices could have a substantial impact on reducing water demand and alleviating water stress. In 2018, approximately 36.6 % of the water allocated for group agricultural use was sourced from underground sources. Despite annual variations, the volume of groundwater granted for this purpose increased by 18.0 % compared to 2009 (CONAGUA, 2019). The current water extraction rights in agriculture lack consistent payment obligations, resulting in a lack of administrative payments. This oversight encourages excessive groundwater utilization by farmers, disregarding long-term sustainability. To promote responsible and efficient water use in agriculture, it is crucial to determine the actual costs linked to groundwater extraction.

4.3 Water should be treated as having an economic and social value.

Recognizing and valuing water both economically and socially is crucial for effective water management. This paradigm shift acknowledges water as a finite resource with intrinsic worth, playing a vital role in societal well-being and economic development (Yu Wang et al., 2022). Assigning value to water enables decision-makers to prioritize its efficient and responsible allocation, incentivize conservation, promote sustainability, and ensure equitable access. A comprehensive reassessment of current practices is necessary to identify and rectify systemic deficiencies hindering sustainable water management.

4.4 Public awareness about water management

Raising awareness about responsible water use, conservation, and the challenges of water scarcity is crucial for effective water management (Briseño & Sánchez, 2018). This can be achieved through targeted educational campaigns, public outreach programs, and the dissemination of accurate information on water resources. Transparent information on urban water sources fosters connection and responsibility among residents (Zamora Sáenz & Sánchez Gálvez, 2020). Promoting awareness of water sources empowers individuals to make informed choices and contribute to sustainable water management.

Understanding current and projected water availability is essential to address water scarcity. Comprehensive and up-to-date data identify scarcity hotspots and inform conservation efforts, efficient water use practices, and alternative water sources. Participatory governance ensures long-term water management sustainability (Yu Wang et al., 2022).

4.5 Address inequitable distribution and inefficient water use

The inefficient use and inequitable distribution of water in Mexico contribute not only to significant resource wastage but also to growing socio-political tensions. These issues are particularly pronounced in the irrigation sector and in regional water distribution systems, where disparities in allocation generate a sense of deprivation and marginalization among specific communities. Such imbalances not only undermine social cohesion but also promote unsustainable water practices and poor resource use. Effectively addressing these challenges requires a differentiated, regionally tailored approach that accounts for hydrological, demographic, and economic asymmetries. Disparities are particularly acute in northern and central Mexico, which host more than 77 % of the national population and generate over 82 % of the country's GDP, yet suffer from the lowest levels of water availability (Arreguín-Cortés et al., 2020). These regions must therefore be prioritized in the design and implementation of national water policies.

The degradation of water quality further exacerbates the problem. According to data from CONAGUA, over 70 % of surface water bodies in Mexico exhibit some degree of contamination, largely due to untreated municipal wastewater, industrial discharges, and agricultural runoff (Cervantes-Jiménez et al., 2020; CONAGUA, 2022). This environmental deterioration jeopardizes both public health and ecosystem integrity, particularly in areas of high agricultural and industrial activity. Consequently, integrated water resource management must address both the quantity and quality dimensions of water governance. Institutional and technical improvements are required to support better decision-making. This includes the development of robust, up-to-date databases on water availability, use, and quality at the basin and municipal levels. Accurate and timely information is essential for monitoring progress, identifying critical areas, and designing responsive programs tailored to specific regional conditions (Chen & Bilton, 2022).

Investments in scientific research and technological development are key drivers of improved water governance. Expanding the application of precision metering, geospatial monitoring systems, and real-time analytics will enhance the detection of inefficiencies, track losses, and support performance-based management (Janjua et al., 2021). These technologies enable the systematic collection of data on consumption patterns, aquifer levels, contamination hotspots, and infrastructure performance. Valuable insights gained from these measurements will inform decision-makers and enable targeted interventions to reduce losses and enhance overall water management efficiency (Sánchez et al., 2022). The use of verified technical information enables more equitable resource distribution, supports the prioritization of infrastructure investments, and informs conservation efforts aligned with regional needs. Ultimately, aligning technological advancement with institutional coordination and political commitment offers a viable path to addressing inefficiencies, rectifying distributional inequities, and ensuring long-term water security for all sectors of society.

4.6 Tariff structure and financial considerations for improved water management

Most WU in Mexico do not cover operating expenditures with revenues from tariffs; the two main reasons for this are poor operating efficiency and tariffs that are not sufficient to cover reasonable costs of service (CONAGUA, OECD, and IMTA, 2010). To address these challenges, it is essential to design a modern tariff structure that reflects the real cost of water production and delivery while accounting for user consumption patterns and financial sustainability (Camacho & Casados, 2017). Establishing tariff rates that reflect the true economic value of water is imperative. Adequate and reasonable rates not only secure the financial viability of service providers but also enable them to maintain, rehabilitate, and expand infrastructure to meet growing demand (Briseño & Sánchez, 2018). Without such adjustments, utilities remain dependent on public subsidies, thereby constraining their capacity to operate autonomously and efficiently. In parallel, transparency in the methodologies and criteria used to determine tariffs must be strengthened to promote user trust and institutional accountability.

The agricultural sector, which holds 76 % of all potable water concessions and consumes most of the national water supply, presents a particular challenge. It is essential to move toward the implementation of cost-recovery pricing for agricultural water use, structured according to consumption volumes, user category, and aquifer condition. Differentiated pricing would serve as an economic signal to encourage water-saving practices among both large and small-scale users. Moreover, the current subsidy system disproportionately benefits high-volume users rather than vulnerable populations (IMCO, 2023). Redesigning subsidies to ensure that low-income households and small agricultural producers receive targeted support would enhance equity without compromising environmental sustainability. Rates that fail to reflect the full cost of supply are often compensated by federal transfers; however, this model is not sustainable in the long term, especially under conditions of increasing water scarcity and climate variability.

Electricity tariffs for groundwater pumping, particularly in overexploited aquifers, must also be revised (CONAGUA, OECD, and IMTA, 2010). Establishing consumption-based brackets can encourage more rational use. Low-consumption users would benefit from preferential rates, while high-volume consumers and operations in stressed aquifers would pay proportionally higher rates. Similarly, water tariffs in the industrial sector should be subject to annual evaluations that account for regional water stress, aquifer status, and supply-demand dynamics. This would help determine whether current pricing is sufficient to finance operations and incentivize more efficient use. A key institutional improvement lies in strengthening the role of CONAGUA in collecting, updating, and analyzing information related to tariffs, including the methodologies used by each entity. Comprehensive and transparent databases would allow for evidence-based reviews and rate adjustments that respond to changing hydrological and economic conditions. To ensure that tariff collection aligns with expenditure responsibilities, enhanced coordination is needed between CONAGUA and the Ministry of Finance (SHCP). State-level planning must consider future scenarios of drought, population growth, and water stress to allocate resources more equitably and strategically, prioritizing the region's most at-risk (IMCO, 2023). In turn, municipalities should be supported through technical training and institutional development programs aimed at modernizing their billing, metering, and monitoring systems. Upgrading these administrative and technical capabilities would increase collection efficiency, reduce losses, and foster greater user compliance through accurate measurement and timely billing (Yu Wang et al., 2022).

Ultimately, revising the tariff structure and addressing financial bottlenecks are indispensable steps toward achieving universal, efficient, and resilient water services. An integrated, transparent, and performance-based approach to pricing will ensure that the sector is adequately funded while promoting conservation, equity, and sustainability (CONAGUA, OECD, and IMTA, 2010).

4.7 Sustainable growth in relation to water resources

The adoption of a new management model is necessary for sustainable growth. This model should prioritize self-sustainability and quality of service, placing a strong emphasis on water safety and the long-term viability of water resources. By integrating innovative approaches and advanced technologies, can ensure the provision of high-quality water services that effectively meet the needs of the population (IMTA & SEMARNAT, 2018). Improving water availability predictions and establishing independent monitoring systems are vital steps towards efficient resource allocation. Accurate predictions of water availability enable informed decision-making, ensuring optimal utilization of the available resources. Additionally, developing mechanisms for incorporating cities into watershed management is essential. Recognizing the impact of urban areas on surrounding watersheds, collaborative efforts between cities and water management entities can lead to improved water resource management and environmental sustainability (Cotler et al., 2022). By integrating urban planning, stormwater management, and wastewater treatment into watershed management strategies, Mexico can optimize water usage and mitigate the negative impacts of urbanization on watersheds. To ensure sustainable development, it is crucial to align development activities with technical studies regarding water availability. Decision-making processes should be based on sound scientific evaluations that consider the availability of water resources (Mumbi et al., 2021; Yu Wang et al., 2022). By incorporating these studies into development planning, Mexico can harmonize growth and economic activities with the available water resources, minimizing negative impacts on the environment.

4.8 Improve WU

Inefficient water management practices and financial challenges faced by WU undermine the sustainability of the water sector (Chopra & Ramachandran, 2021). The significant losses of drinking water contribute to financial insolvency, health risks, and environmental degradation, emphasizing the urgency for corrective measures. In Mexico's WU, the physical efficiency is only 52.7 %, resulting in 47.3 % of water being unbilled due to leaks. Moreover, the commercial efficiency stands at 76.3 %, indicating that approximately a quarter of billed water remains uncollected. These losses have detrimental effects on the financial viability of WU, as their average income covers only part of the production costs, necessitating government subsidies to bridge the gap (Briseño & Sánchez, 2018). Strengthening governance structures and exploring innovative funding mechanisms are necessary to address economic deficits and ensure financial stability. Establishing a stable legal framework that empowers operating organizations to fulfill their technical, operational, administrative, financial, and investment functions is essential (Zamora Sáenz & Sánchez Gálvez, 2020). Ensuring returns on investment and generating resources for technological advancements, infrastructure rehabilitation, and equipment automation are vital for service improvement and cost optimization (IMTA & SEMARNAT, 2018; Arreguín-Cortés et al., 2020).

In addition to addressing economic challenges, enhancing service quality is crucial to meet growing demands and user expectations. Infrastructure improvements, operational optimizations, and robust monitoring systems should be prioritized to enhance reliability and customer satisfaction (Camacho & Casados, 2017). To achieve efficient WU, it is essential to professionalize the personnel in key positions within the organization. By investing in the professional development of staff, the agencies can make informed decisions and implement water management strategies that align with best practices. Involving civil society experts in water management governance is vital (Hernández-Cruz, et al. 2022). Establishing an autonomous institution with multidisciplinary experts ensures comprehensive decision-making based on technical criteria rather than political interests. The absence of comprehensive policies and effective institutions regulating WU hinders progress (González-Villarreal & Arriaga-Medina, 2014; Briseño & Sánchez, 2018). It is imperative to establish robust regulatory frameworks and governing bodies to enforce standards in the water sector.

4.9 Improve public policy

The current fragmented nature of policies and regulations poses significant challenges to the sustainable use and allocation of water resources. To overcome this, Mexico needs to streamline and harmonize the legal framework on water and environmental matters, creating a unified approach that encourages integrated water management strategies across all levels of governance. Addressing the complex issue of water allocation requires collaborative efforts and consensus among stakeholders (IMCO, 2023). Establishing a national framework for water allocation, where decisions are made collectively while considering the diverse needs and priorities of various sectors and regions, is crucial. An essential aspect of achieving effective water management is improving the water rights allocation system. The current system has several gaps, such as unauthorized water uses and inefficient allocation mechanisms (CONAGUA, OECD, and IMTA, 2010). To rectify these issues, Mexico must revisit and refine the system, implementing a fair and transparent water rights allocation system.

The legal framework at the federal, state, and municipal levels plays a pivotal role in shaping water management practices. Modifying the water policy is necessary to strengthen the objectives and strategies of water management institutions. Furthermore, amending the General Water Law will provide a robust legal foundation that can effectively address emerging challenges and promote sustainable water practices in Mexico (Zamora Sáenz & Sánchez Gálvez, 2020). To ensure effective water management, it is vital to strengthen governance structures. This involves enhancing institutional capacities, promoting transparency, and fostering meaningful stakeholder engagement. A critical aspect of water management in Mexico involves reviewing and updating the water sharing agreements of transboundary basins (Zamora Sáenz & Sánchez Gálvez, 2020). As water resources do not conform to political boundaries, collaborative agreements between neighboring countries are essential. By revisiting and updating these agreements, Mexico can address emerging challenges, adapt to changing circumstances, and foster equitable and sustainable water sharing practices.

5. Conclusion

Mexico faces persistent challenges in the sustainable management of its water resources, entrenched in a historical imbalance between availability and demand, institutional fragmentation, and chronic underinvestment in infrastructure and governance. Despite ongoing reforms, inefficiencies in service delivery, financial deficits in water utilities, and unequal access, particularly in arid and densely populated regions, continue undermining water security. These issues are further compounded by climate variability, aquifer depletion, and widespread water quality degradation. Overcoming these challenges requires integrated, basin-scale planning; strengthened inter-institutional coordination; and the implementation of equitable, efficiency-driven policy instruments. Enhancing local governance, modernizing tariff structures to promote financial sustainability, and adopting data-informed management tools are essential to improving service reliability and resilience. Crucially, a management model centered on self-sufficiency, water security, and long-term urban and watershed viability must be adopted. Institutional reforms should prioritize transparency, accountability, and democratic participation in decision-making processes. Through such structural transformations, Mexico can advance toward sustainable water governance, ensuring the protection, equitable distribution, and long-term viability of its water resources. The scope of this article is limited to disclosing the current performance and governance capacity of Mexico's water institutions; therefore, while regulatory frameworks and water quality standards are acknowledged, their detailed technical evaluation and comparative analysis with international cases lie beyond its purpose. Future research should address these dimensions to complement institutional perspectives and provide a more comprehensive understanding of water governance.

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Conflict of interest

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